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(54) Title: HIGH EFFICIENCY EMITTER FOR INCANDESCENT LIGHT SOURCES

(57) Abstract: An emitter (F) for incandescent light sources, in particular a filament, capable of being brought to incandescence by the passage of electric current is obtained in such a way as to have a value of spectral absorption  $\alpha$  that is high in the visible region of the spectrum and low in the infrared region of the spectrum, said absorption  $\alpha$  being defined as  $\alpha=1-\rho-\tau$ , where  $\rho$  is the spectral reflectance and  $\tau$  is the spectral transmittance of the emitter.

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**"High efficiency emitter for incandescent light  
sources"**

**TEXT OF THE DESCRIPTION**

**Field of the invention**

5       The present invention relates to an emitter for incandescent light sources, in particular shaped as a filament or a plate, capable of being brought to incandescence by the passage of electric current.

**Background of the invention**

10       As is known, traditional incandescent lamps are provided with a tungsten (W) filament which is made incandescent by the passage of electric current. The efficiency of traditional incandescent lamps is limited by Planck's law, which describes the spectral intensity  
15        $I(\lambda)$  of the radiation emitted by the tungsten filament of the lamp at the equilibrium temperature  $T$ , and by heat losses through conduction and convection. The energy irradiated by the tungsten filament in the visible range of the electromagnetic spectrum is  
20       proportional to the integral of the curve  $I(\lambda)$  between  $\lambda_1=380$  nm and  $\lambda_2=780$  nm, and is at the most equal to 5-7% of the total energy.

      According to Kirchoff's law, under thermal equilibrium conditions the electromagnetic radiation  
25       absorbed by a body at a specific wavelength is equal to the electromagnetic radiation emitted. A direct consequence of this law is that the spectral emittance " $\epsilon$ " of a surface coincides with spectral absorbance " $\alpha$ ". Spectral absorbance " $\alpha$ " in turn is linked to  
30       spectral reflectance " $\rho$ " and to spectral transmittance " $\tau$ " through the relationship  $\alpha=1-\tau-\rho$  whence descends the relationship  $1-\epsilon=\tau+\rho$ . For an opaque material,  $\tau$  is substantially nil and spectral reflectance  $\rho$  coincides with  $(1-\epsilon)$ ; note, however, that any material, for  
35       sufficiently small thickness values, has a spectral

transmittance  $\tau$  different from 0:

The relationship  $\tau + \rho = 1 - \varepsilon$  implicitly states that, if the surface of an opaque body has a low spectral reflectance at a given wavelength, the corresponding  
5 spectral emissivity will be very high; vice versa, if spectral reflectance is high, the corresponding emissivity will be low.

Emissivity, absorbance, transmittance and reflectance are functions, not only of wavelength, but  
10 also of temperature  $T$  and of the angle of incidence/emission  $\theta$ , but the above relationships hold true for any  $T$ , any wavelength and any angle, since they descend from pure thermodynamic considerations. In general, the relationship  $\tau + \rho = 1 - \varepsilon$  can thus be rewritten  
15 as

$$\tau(\lambda, T, \theta) + \rho(\lambda, T, \theta) = 1 - \varepsilon(\lambda, T, \theta).$$

The curves of reflectance and spectral transmittance at a given temperature  $T$ , from which descend the values of absorbance and emissivity at that  
20 temperature, can be calculated a priori through the optical constants (always at temperature  $T$ ) of the material or of the materials constituting the emitter for any geometry of the emitter and for any angle of incidence/emission.

25 The optical constants of the material are the real value  $n$  and the imaginary value  $k$  of the refraction index; the values of  $n$  and  $k$  for most known materials have been measured experimentally and are available in the literature. In general, there are no values of  $n$   
30 and  $k$  available at the temperatures of interest for incandescent sources. The reflectance and transmittance calculation, presented in the remainder of the description and in the related figures, refer to optical constants measured at ambient temperature;  
35 however, the above considerations have general validity

and can easily be transferred to the case of high temperatures.

In a traditional incandescent source, radiation is emitted by a tungsten filament, whose operating temperature is around 2800K; the emitted radiation follows the law of the black body, whose corresponding spectrum is given by Planck's relationship. The filament can be considered, with good approximation, a grey body, i.e. with constant emissivity throughout the spectrum of interest. By definition, a black body is a grey body with emissivity  $\varepsilon(\lambda, T, \theta)$  independent of  $\lambda$  and of  $\theta$  and equal to 100% (maximum value). The emission spectrum of a grey body can be obtained multiplying the black body spectrum  $I(\lambda)$  (given by Planck's relationship) for an emissivity value of  $\varepsilon(T)$ . For a non-grey body, Planck's curve  $I(\lambda)$  must instead be multiplied times a spectral emissivity curve  $\varepsilon(\lambda, T, \theta)$ .

The spectral emissivity of tungsten is generally a function of temperature; it has been demonstrated empirically that the mean emissivity of tungsten follows the relationship

$$\varepsilon_m(T) = -0.0434 + 1.8524 \cdot 10^{-4} \cdot T - 1.954 \cdot 10^{-8} \cdot T^2.$$

At low temperatures the spectral emissivity curve can easily be derived measuring the reflectance spectrum of tungsten and applying the relationship  $\varepsilon(\lambda, T, \theta) = 1 - \rho(\lambda, T, \theta)$ ; at incandescence temperatures, this type of measure becomes unfeasible, because the spectrum of reflectance and the spectrum of emission are obviously mixed.

At the temperature of 2800K, the mean emissivity of tungsten is about 30%, which corresponds to a mean reflectance of about 70%. At 2800K, the peak in the emission spectrum is at a wavelength slightly greater than 1 micron, which presupposes that most of the

radiation is emitted in the form of infrared.

In particular for a grey body at a temperature of 2800K, slightly less than 10% of radiation is emitted in the visible spectrum (380-780 nm), whilst over 20% is emitted in near infrared (780-1100 nm).

In fact, the tungsten filament is not an actual grey body, but it has a spectral emissivity that is more or less constant in the visible spectrum, and tends significantly to decrease in near infrared, as is readily apparent from the reflectance and spectral emissivity curves shown in Figure 1. In the graph of Figure 1, the curves CRW and CEW respectively represent the reflectance and the emissivity of tungsten at ambient temperature for different wavelengths in the visible and near infrared spectrum.

This causes the efficiency of a tungsten filament, i.e. the ratio between visible radiation and total emitted radiation, is far greater than that of a grey body; the advantage is still more significant when considering the spectral emissivity at ambient temperature. Figure 2 compares the Planck's curve at 2800K, designated CP, with the spectral power emitted by a tungsten filament at 2800K; for tungsten, the chart shows both the experimentally measured values (curve PM), and the values calculated using the optical constants of tungsten at ambient temperature (curve PC).

#### Summary of the invention

Based on the above, the present invention aims to provide an emitter for incandescent sources, capable of being brought to incandescence by a passage of electric current, having a higher efficiency than filaments for incandescent lamps obtained with traditional techniques.

The term "efficiency of the light source" means the

ratio between the visible component (i.e. the component between 380 nm and 780 nm) of the electromagnetic radiation and the sum between the visible component and the near infrared component (i.e. the component between 780 nm and 2300 nm).

This object is achieved by an emitter for incandescent light sources, capable of being brought to incandescence by the passage of electrical current, provided with means for maximising absorbance  $\alpha(\lambda)$  for  $\lambda$  belonging to the visible region of the spectrum and minimising absorbance  $\alpha(\lambda)$  for  $\lambda$  belonging to the infrared region of the spectrum, in such a way that, at equal operating temperature  $T$ , the ratio between the radiation emitted in the visible region of the spectrum and the radiation emitted in the infrared region of the spectrum of the emitter is greater than the same ratio for a tradition incandescent filament.

The aforesaid means comprise a nanostructure formed on at least one surface of the emitter, comprising an ordered series of micro-projections and/or of micro-cavities and permanently encapsulated in a dielectric matrix of refractory material, such as alumina, yttria, zirconia, or any other oxide with high melting point.

The nanostructuring of the emitter surface is aimed at obtaining a relative increase in emissivity (or decrease in reflectance) in the visible region of the spectrum, to a greater extent than the relative increase in emissivity (or decrease in reflectance) in the infrared region of the spectrum.

The aforesaid matrix of refractory oxide, instead, has the dual function of:

- i) limiting the atomic evaporation of the material constituting the emitter, or its nanostructure, at high operating temperature, responsible for the "notching" effects of the emitter, which shorten its working life

under operating conditions, and also for the nanostructure flattening effects; said evaporation, which is the greater the higher the operating temperature, would tend to flatten the superficial structure of the emitter, reducing its performance over  
5 time and its benefits in terms of efficiency increase;

ii) maintaining the morphological structure of the emitter, or of its nanostructure, even if the material which constitutes it undergoes a state change, in  
10 particular melting, due to its use under conditions of operating temperature exceeding its melting point.

The aforementioned item ii) has a particular importance because it allows to use materials having, in the presence or absence of superficial structuring, a spectral emissivity that is particularly high in the  
15 visible region and low in the infrared, even at operating temperatures exceeding the melting point; for such materials, in spite of the good spectral emissivity properties, luminous efficiency would  
20 otherwise be limited by their use at low temperature (as is well known, the visible component emitted by a grey body grows as temperature grows, reaching the maximum point at  $T$  of about 6000K, the surface temperature of the Sun).

25 To increase the spectral absorption of the emitter in the visible region and minimise spectral absorption in the infrared region, the choice of the material whereof the emitter is made is at least as important as the morphology of the microstructure obtained on the  
30 emitter.

Purely by way of example, a material such as gold has a spectral emissivity at room temperature that is particularly suited to obtain an efficient emitter, since spectral reflectance in the near infrared region  
35 is very high and drops suddenly in the visible region.

of the spectrum (hence the yellow colour, due to high absorption in the blue portion). In this regard, see Figure 1 where the curve CRAu represents the reflectance of a gold foil, which is sharply higher than planar tungsten as per curve CRW in the near infrared region, and with a much more sudden drop in the visible region with respect to tungsten; in said Figure 1, the curve CEAu represents the emissivity of the same gold foil. The efficiency (as previously defined) of a planar tungsten emitter at 2000K is about 6%, whilst that of a planar gold emitter is about 8% (superficial temperature of 2000K, greater than the melting point of gold).

As stated, the solution according to the present invention consists of structuring the surface of the emitter, which is preferably in plate form with parallel faces, but can also be in the form of a wire, cylindrical or with any other cross section, with the three-dimensional micro-structure having periodicity below the visible wavelength and such as to increase absorption selectively, mainly in the visible region of the spectrum. This allows, at equal equilibrium temperature, to increase the portion of radiation emitted in the visible region, increasing the portion emitted in the infrared region to a lesser extent than the visible portion and thereby enhancing the luminous efficiency of the emitter. In general terms, the dimensions of the emitter according to the invention, both in terms of total thickness and of depth/height of the micro-projections or of the micro-cavities, are in the order of tens or hundreds of nanometres. The size and periodicity of the micro-structure are determined according to the real and imaginary refraction index of the material used, to the operating temperature and to the spectral reflectance curve to be obtained.



It should be observed that the spectral reflectance curve depends not only on the structure of the anti-reflection grating provided, but also on the angle of incidence and polarisation of the light. The anti-  
5 reflection micro-structure according to the invention can be optimised as a function of a specific angle of incidence (typically, normal incidence) and of a polarisation state, which means that the reflectance curve will in fact be optimised only for one specific  
10 angle of incidence. However, the grating can be optimised, in terms of pitch, height and shape of the micro-projections or of the micro-cavities, in such a way as to minimise the angular sensitivity of the grating.

15 Specific preferred characteristics of the invention are set out in the appended claims, which are understood to be an integral part of the present description.

#### Brief description of the drawings

20 Additional objects, characteristics and advantages of the invention shall become readily apparent from the description that follows, made with reference to the accompanying drawings, provided purely by way of non limiting examples, in which:

25 - Figure 1 is a chart which represents the reflectance (curve CRW) and the emissivity (curve CEW) of tungsten at ambient temperature for different wavelengths in the visible and near infrared spectrum, compared with the spectral reflectance (curve CRAu) and  
30 emissivity (curve CEAu) of gold;

- Figure 2 is a chart which compares Planck's curve at 2800K (curve CP) to the spectral power emitted by a tungsten filament at 2800K; for tungsten, the chart shows both experimentally measured values (curve PM),  
35 and the values calculated using the optical constant of

tungsten at ambient temperature (curve PC);

- Figure 3 is a schematic perspective representation of a portion of an emitter superficially provided, according to the invention, by a one-dimensional diffraction grating, i.e. with periodic projections along a single direction;

- Figures 4 and 5 are schematic perspective representations of respective portions of two emitters according to the invention, superficially provided with a respective two-dimensional diffraction grating, i.e. with periodic projections along two orthogonal directions on the surface of the emitter;

- Figure 6 is a schematic perspective representation of a portion of a further emitter according to the invention, superficially provided of a two-dimensional diffraction grating with rhombic symmetry, formed by periodic cavities along two not orthogonal directions on the surface of the emitter;

- Figure 7 is a chart comparing the spectral emissivity of planar tungsten (curve CEW) and that of tungsten nanostructured with a grating of the kind shown in Figure 3 (curve CEW');

- Figure 8 is a chart comparing the spectral emissivity of planar gold (curve CEAu) and that of gold nanostructured with a grating of the kind shown in Figure 3 (curve CEAu');

- Figure 9 is a chart showing the relative increase in spectral emissivity as a function of wavelength for a tungsten emitter nanostructure with a grating of the kind shown in Figure 3;

- Figure 10 is a chart showing the relative increase in spectral emissivity as a function of wavelength for a gold emitter, nanostructured with a grating of the kind shown in Figure 3;

- Figures 11 and 12 are schematic sectioned

representations of respective portions of emitters in accordance with two preferred embodiments of the invention, superficially provided with a respective two-dimensional diffraction grating and encapsulated in  
5 a refractory oxide;

- Figure 13 is a schematic representation of an emitter according to the invention formed by a nanostructured support (W) which is coated by a thin layer (Au) of material, not necessarily with high  
10 melting point, such as gold, silver, copper, and by at least an upper encapsulating layer constituted by a refractory oxide (OR);

- Figure 14 is a schematic representation of an emitter according to the invention in which the nanostructuring is formed in a layer (Au) made of material with low melting point, such as gold, silver copper, which is deposited onto a planar substrate (W) of material with high melting point, such as tungsten, and also encapsulated, at least superiorly, in a layer  
15 of refractory oxide (OR);

- Figure 15 is a schematic representation of an emitter according to the invention in which the nanostructure grating is obtained on refractory oxide (OR), and said grating is superficially coated by a layer (Au) of material with low melting point, such as gold, silver, copper, the layer with low melting point being in turn coated by an additional layer of refractory oxide.  
20

#### Detailed description of the invention

30 As previously explained, according to the main aspect of the present invention, the increase in efficiency of visible emission is obtained by means of an appropriate micro-structuring of the surface of the incandescence emitter; said micro-structuring is  
35 operative to reduce the reflectance  $\rho$  in the visible

region of the spectrum, reducing the reflectance  $\rho$  in the near infrared region to a lesser extent, in order to increase emission efficiency in the visible region.

The desired anti-reflection behaviour can be  
5 obtained both with a one-dimensional grating, i.e. with periodic projections along a single direction on the surface of the filament, both with a two-dimensional diffraction grating, i.e. with periodic projections  
10 along two orthogonal directions, not being necessarily parallel to each other, on the surface of the filament. For this purpose, in Figure 3 the reference F designates a portion of an emitter according to the invention, which superficially has a diffraction  
15 grating R formed by periodic micro-projections R1 along a single direction; in the case shown in Figures 4 and 5, instead, the portion F of emitter according to the invention superficially has a diffraction grating R formed by periodic micro-projections R2 along two  
20 orthogonal directions. It should be noticed that the anti-reflection structure R could have also different symmetries, such as a rhombic, hexagonal or any other type of symmetry.

In Figures 3-5, the reference h designates the depth or height of the projections R1, R2, the  
25 reference D designates the width of the projections and P the period of the grating R; the filling factor of the grating R is defined as the ratio  $D/P$  in the case of Figure 3, as the ratio  $D^2/P^2$  in the case of Figure 4 and as the ratio  $\pi D^2/(4P^2)$  in the case of Figure 5.

30 Figure 6 shows a portion F of an emitter according to the invention whose superficial diffraction grating R is instead formed by micro-cavities C periodic along two orthogonal directions, being not necessarily parallel to each other; in substance, the anti-  
35 reflection structure as proposed in Figure 6 has a

shape that is complementary to the shape of the structure shown in Figure 5.

In general, the anti-reflection grating according to the invention can also be multi-level or with  
5 continuous profile, which allows to increase the degrees of freedom to optimise the grating and further enhance efficiency.

According to a further important aspect of the invention, the diffraction grating R is permanently  
10 encapsulated in a layer of refractory oxide, for instance yttrium oxide; the presence of said layer of oxide has many advantages:

- it enables further to enhance the efficiency of the emitter, itself acting as an anti-reflection  
15 coating able to complement the anti-reflection characteristics of the diffraction grating R;

- it can enable to operate the filament under less pronounced vacuum conditions or, in principle, even in air without encountering phenomena of oxidation of the  
20 emitter F;

- both under vacuum and inert gas atmosphere conditions, the presence of the oxide coating allows to reduce the evaporation rate of the material constituting the emitter, and hence extend the average  
25 life of the source and preserve the shape of the micro-structure R;

- it allows to use materials whose optical constants are better suited for the manufacture of high efficiency emitters, such as gold, even at operating  
30 temperatures exceeding the melting point of the material itself (but still lower than the melting point of the refractory oxide) encapsulating said materials and assuring that the structural morphology of the emitter F is maintained.

35 From the preceding description, and from Figures 7.

and 9 (where the curve CEW represents the spectral emissivity of planar tungsten and the curve CEW' that of tungsten nanostructured according to the invention), it is readily apparent that, by virtue of the anti-reflection nanostructuring of the emitter F, at equal operating temperature T, the ratio between the radiation emitted in the visible region of the spectrum and the total radiation emitted in the visible and infrared region of the spectrum for an emitter according to the invention is greater than the same ratio with respect to the case of a traditional incandescent filament, with obvious advantages in terms of light source efficiency. In particular, given that the proposed emitter has a respective spectral absorbance  $\alpha(\lambda, T)$  at an operating temperature T and for a wavelength  $\lambda$ , (where absorbance is linked to spectral reflectance  $\rho(\lambda, T)$  and to spectral transmittance  $\tau(\lambda, T)$  by the relationship  $\alpha(\lambda) = 1 - \rho(\lambda, T) - \tau(\lambda, T)$ ), the anti-reflection structure R enables to maximise absorbance  $\alpha(\lambda)$  for  $\lambda$  belonging to the visible region of the spectrum, whereas absorbance  $\alpha(\lambda)$  for  $\lambda$  belonging to the infrared region of the spectrum is increased by a lesser extent.

The proposed microstructure R according to the invention is therefore suitable to modify the spectral emissivity of the emitter F, increasing the portion of emitted visible light, and hence the luminous efficiency of the lamp or light source which incorporates said emitter. In this view, the micro-projections R1, R2 or the micro-cavities C will be conceived to maximise the electromagnetic emission in the visible spectrum from emitter F, without reducing and, in fact, possibly increasing reflectance in other spectral regions.

As explained above, the operation of the

microstructure R is based on Kirchoff's law, according to which under thermal equilibrium conditions the electromagnetic radiation absorbed by a body at a specific wavelength is equal to the emitted electromagnetic radiation. A direction consequence of this law is that if the surface of a body has low spectral reflectance at a given wavelength, the corresponding spectral emissivity will be very high; vice versa, if spectral reflectance is high, the corresponding emissivity will be low.

The dependence of spectral reflectance on the angle and on the polarisation state impacts on a similar angular dependency of spectral emissivity, based on the above considerations. Thus, considering the radiation emitted by the superficially micro-structured emitter according to the invention, at a specific wavelength, the corresponding emission lobe will not be Lambertian (constant radiance, as in the case of unstructured source), but will follow the angular behaviour of the grating given by the microstructure R. The emitted radiation, moreover, will have a degree of polarisation and coherence, unlike the radiation emitted by an incandescent source according to the prior art.

The advantages described above can be obtained to a greater extent by means of nanostructured emitters constructed with materials having more favourable optical constants than tungsten.

In this regard see, for example, Figure 8, in which the spectral emissivity of planar gold (curve CEAu) is compared to that of gold nanostructured with a grating R according to the invention, and Figure 10, which shows the relative increase in spectral emissivity as a function of wavelength for a gold emitter nanostructured according to the invention.

On this point it should be recalled that many

materials with lower melting points than tungsten, such as gold, silver, copper, have more advantageous emissive properties than tungsten, although their low melting point normally precludes their use at operating  
5 temperatures where visible emission is efficient (>1500K); as stated previously, to obtain an advantageous black body emission (i.e. one with a greater visible emission), the body must be taken to the highest possible temperatures (maximum efficiency  
10 above 5000K). In the case of emitter materials with low melting point, the material itself can melt or at least be deformed as the current that brings to incandescence passes, which would entail the loss of the grating shape capable of enhancing emission efficiency, until  
15 the emitter is completely destroyed.

In the preferred embodiment of the invention, therefore, a refractory oxide is used to encapsulate the filament provided with the grating, in such a way that the softening or even the passage to the liquid  
20 state of the nano-structured conductor material does not entail the destruction of the grating, and ultimately of the emitter. The refractory oxide, which is non deformable at the temperature of incandescence of the emitter (1500K-2000K depending on the material)  
25 in fact constitutes a complementary matrix to the anti-reflection grating and it is therefore capable of maintaining the shape thereof even if the material constituting the emitter is deformed or liquefied. In this way, the performance of the grating is assured and  
30 the behaviour of the a priori designed emission is maintained, as explained above.

In accordance with the aforesaid preferred embodiment, the emitter or a part thereof is made with a conductor or semiconductor with low melting point,  
35 but having optical constants that are suitable.



significantly to enhance the efficiency of the emitter through an appropriate nanostructuring. Conductor material of particular interest in this sense are for instance gold, silver and copper.

5 As is readily apparent from a comparison between Figures 7-8 and 9-10, the effects of the superficial microstructure of the emitter on efficiency enhancement are definitely more significant in gold than in tungsten. The efficiency of a tungsten emitter,  
10 appropriately structured and coated by yttrium oxide, at 2000K is almost 8% (i.e., 20% relative increase), whilst a structured gold emitter, encapsulated in yttria to be able to maintain its structural morphology even above the melting point, increases its efficiency  
15 with respect to planar gold by over 200%, achieving an efficiency of 25%.

Figures 11 and 12 are partial and schematic representations of two emitters F according to the preferred embodiment described above, which extend  
20 between respective electrodes H.

In the case of Figure 11, the emitter F has an anti-reflection structure R of the type shown in Figure 5, constituted by substantially cylindrical micro-projections or pillars R2, whilst in the case of Figure  
25 12 the structure R is of the type shown in Figure 6, constituted by micro-cavities C having circular cross section. The emitter F is structured in such a way as to obtain a two-dimensional phase grating, for instance made of gold, in which the electrical current that  
30 induces incandescence passes. The electrodes H are instead made of a high melting point conductor material, such as tungsten and the like, or semiconductor material, such as carbon and the like.

The low melting point material of the emitter F  
35 traversed by current reaches high temperature; for .

example, in the exemplified case, in which the material of interest is gold, the radiation is emitted by the emitter at an operating temperature around 1900-2000 degrees Kelvin. As previously explained, at such  
5 temperatures a gold grating would be liquefied. According to the preferred embodiment, therefore, the layer of refractory oxide is provided, designated by the reference OR in Figures 11 and 12, which fully coats the emitter F, following its profile in its  
10 structured part R; in other words, the refractory oxide R is the perfect female 8 in the case of structure with micro-projections R2) or the perfect male (in the case of structure with micro-cavities C) of the grating R.

The oxide OR with high melting temperature can for  
15 instance be a ceramic base oxide, thorium, cerium, yttrium, aluminium, zirconium oxide.

When the metallic grating R is deformed and/or melted, the oxide matrix OR preserves the phase profile of the grating R, i.e. assures that its shape is  
20 maintained, even if the material constituting the emitter reaches the liquid state.

In a particularly advantageous embodiment, one or more throats or cavities G are provided, open on the material of the emitter F, for example in  
25 correspondence with one or both electrodes as schematically shown in Figure 11, or within the refractory oxide structure, as schematically shown in Figure 12. Such cavities or throats G are provided to be filled by the material of the emitter F whose volume  
30 can expand at high temperatures; said throats G therefore serve to prevent delamination phenomena between the oxide OR and the material of the emitter F, as well as ruptures of the device.

In the various proposed implementations, the micro-  
35 structure R can be obtained directly from the material.

that constitutes the emitter F.

A first possible method provides for the construction of a template made of porous alumina (porous aluminium oxide). For this purpose an aluminium  
5 film, with a thickness in the order of a micron, is plated by means of sputtering or thermal evaporation onto a suitable substrate, for example made of glass of silica, and it is subsequently subjected to an anodisation process.

10 The process of anodising the aluminium film can be carried out using different electrolytic solutions depending on the size and distance of the alumina pores to be obtained.

The layer of alumina obtained by means of the first  
15 anodisation of the aluminium film has an irregular structure; to obtain a highly regular structure, it becomes necessary to carry out successive anodisation processes, and in particular at least

- i) a first anodisation of the aluminium film;
- 20 ii) a step of reducing, by etching the irregular alumina film, conducted by means of acid solutions (such as  $\text{CrO}_3$  and  $\text{H}_3\text{PO}_4$ );
- iii) a second anodisation of the aluminium film starting from the residual part of alumina not  
25 eliminated by means of etching.

The etching step as per item ii) above is important  
to define on the residual part of irregular alumina preferential areas of growth of the alumina itself in the second anodisation step.

30 Conducting the successive operation of etching and anodising several times enables the porous alumina structure to improve until becoming highly uniform.

Once the regular alumina template is obtained, it is infiltrated with the desired emitter material, for  
35 example by means of magnetron sputtering (DC or RF),

i.e. in such a way that the alumina structure serves as a mould for the structured area of the emitter F.

In the case of a tungsten emitter, the alumina structure can subsequently be eliminated in such a way  
5 as to be replaced with a refractory oxide whose melting point is higher than alumina and which can be plated by means of RF sputtering. Vice versa, in the case of an emitter made of material with low melting point and if  
10 the operating temperature of the filament is kept below the melting temperature of alumina, the alumina structure, which is transparent, can be maintained, in order to assure that the shape of the grating R will be maintained at the operating temperatures of the emitter  
15 itself; in this case, on the part of the emitter F that is not structure and protected by the porous alumina will be plated a refractory oxide, in order to provide a globally closed container of the emitter material.

Another possible manufacturing process starts from a filament, or from a planar lamina of the selected  
20 material, and etch the microstructure R under wavelength using any one of the known nanopatterning methods (electronic beam, or FIB or simple advanced photo lithography). In the case of material with low melting point, the emitter thus obtained will be coated  
25 by refractory oxide, for instance by means of sputtering, CVD, electroplating.

In other embodiments, the emitter F according to the invention can be formed with multiple, mutually different materials. For instance, as in Figure 13, the  
30 basic material of the emitter can be a conductor with high melting point, for instance tungsten, designated as W, with the microstructure R obtained directly on said material; on said micro-structure is provided a thin and uniform coating of conductor or semiconductor  
35 material with low melting point and having more

advantageous optical characteristics than tungsten, such as gold, designated by the reference Au; the coating Au allows to maintain the profile of the micro-projection R, whilst exploiting the more favourable emissivity properties of gold; the layer of refractory oxide OR enables to preserve the shape of the structure under conditions of operating temperature exceeding the melting temperature of the layer with low melting point Au. This embodiment also can be provided with a layer of refractory oxide OR on the layer of material W with high melting point, in order to prevent its evaporation and/or oxidation.

In an additional preferred configuration, shown in Figure 14, the micro-structure R can be obtained on a layer of conductor or semiconductor material with low melting point, advantageous from the optical point of view, such as gold, designated by the reference Au, with said layer Au bearing the grating R obtained on a layer of conductor material with high melting point, such as tungsten, indicated by the reference W; in this embodiment, a first layer OR of refractory oxide allows to preserve the shape of the microstructure R in conditions of operating temperature exceeding the melting temperature of the layer with low melting point Au in which the micro-structure itself is formed. In this case, too, a second layer of refractory oxide OR can be provided on the layer of material with high melting point W, in order to prevent its evaporation and/or oxidation.

Both in the configuration of Figure 13 and in that of Figure 14 the electrical current is transported both by the material with high melting point W and by the material with low melting point Au.

In an additional preferred configuration, shown in Figure 15, the micro-structure R can be obtained

directly on a layer of refractory oxide OR; on the layer OR in which the structure R is formed is provided a thin, uniform coating of conductor or semiconductor material with low melting point, such as gold, 5 designated by the reference Au; the layer Au obtained on the microstructure R formed in the oxide OR serves here directly as an emitter or carrier of electrical current; a second layer of refractory oxide OR which coats the layer Au allows to preserve the shape of the 10 structure under conditions of operating temperature exceeding the melting temperature of the layer with low melting point.

Naturally, without altering the principle of the invention, the construction details and the embodiments 15 may vary widely relative to what is described and illustrated, purely by way of example, herein, without thereby departing from the scope of the present invention.

The emitter F described herein can be used to 20 obtain incandescent light sources of various kinds, and in particular for the production of motor vehicle lighting devices. The invention is also suitable for application for the purpose of obtaining planar matrix of micro-sources of incandescent light, where the each 25 of the latter is provided with a respective filament or emitter in accordance with the invention.

CLAIMS

1. An emitter for incandescent light sources,  
capable of being brought to incandescence by means of  
5 the passage of electric current, characterised in that

- on at least one surface of the emitter (F) is  
provided a micro-structure (R) operative to enhance  
absorbance for wavelengths belonging to the visible  
region of the spectrum,

10 - at least a substantial portion of the emitter  
(F), including said micro-structure (R), is coated with  
a refractory oxide (OR) or an oxide with high melting  
point.

2. An emitter as claimed in claim 1, characterised  
15 in that said refractory oxide (OR) is operative to  
preserve the profile of said microstructure (R)

- from effects of evaporation of the respective  
material (W; Au; W, Au) at high operating temperature,  
and/or

20 - in case of deformation or change of state of the  
respective material (W; Au; W, Au), consequent to the  
use of the emitter (F) at operating temperatures  
exceeding the melting temperature of said material (W;  
Au; W, Au).

25 3. An emitter as claimed in claim 2, characterised  
in that the emitter (F) is almost completely coated by  
said refractory oxide (OR), in particular with the  
exception of respective areas for connection to  
terminals (H).

30 4. An emitter as claimed in claim 2, characterised  
in that said micro-structure (R) is made of a  
conductor, semiconductor or composite material (W; Au;  
W; Au), whose optical constants, combined with the  
shape of the micro-structure (R), are such as to allow  
35 a higher luminous emission efficiency than a classic  
incandescence filament, said efficiency being defined :

as the ratio between the fraction of visible radiation emitted at the operating temperature in the interval 380 nm - 780 nm and the fraction of radiation emitted at the same temperature in the interval 380 nm - 2300 nm.

5  
5. An emitter as claimed in claim 2, characterised in that said material (Au) is selected among conductor, semiconductor and composite materials whose melting point is lower than the operating temperature of the filament itself.

10  
6. An emitter as claimed in claim 2, characterised in that it is formed by at least a first layer of conductor material (W), melting at higher temperature than the operating temperature of the emitter (F), such as tungsten, and by a second layer of material (Au) selected among conductor, semiconductor and composite materials whose melting point is lower than the operating temperature of the emitter (F).

20  
7. Emitter as claimed in any of the previous claims, characterised in that said micro-structure (R) is at least partly formed with a material selected among gold, silver and copper.

25  
8. Emitter as claimed in any of the previous claims, characterised in that said refractory oxide (OR) is selected among ceramic base oxides, thorium, cerium, yttrium, aluminium or zirconium oxide.

30  
9. An emitter as claimed in claim 1, characterised in that said micro-structure (R) is obtained by means of a superficial micro-structure of the emitter (F), i.e. in the same material which constitutes the emitter (F).

35  
10. An emitter as claimed in claim 1, characterised in that said micro-structure comprises a diffraction grating (R), having at least one between a plurality of micro-projections (R1, R2) and a plurality of micro-



cavities (C), where the dimensions (h, D) of the micro-projections (R1, R2) or of the micro-cavities (C) and the period (P) of the grating (R) are such as to

- enhance the emission of visible electromagnetic radiation from the material (W; Au; W, Au) constituting at least the micro-structure (R), and/or

- reduce the emission of infrared electromagnetic radiation from the material (W; Au; W, Au) constituting at least the micro-structure (R), and/or

- enhance the emission of the infrared electromagnetic radiation from the material (W; Au; W, Au) constituting at least the micro-structure to a lesser extent with respect to the increase in visible emissivity.

11. An emitter as claimed in claim 10, characterised in that said grating (R) is obtained with

- a first conductor material (W) melting at higher temperature than the operating temperature of the emitter (F), the first material having a structured part,

- a coating layer (Au) which covers at least the structured part of said first material (W), the coating layer being of a second material (Au) selected among conductor, semiconductor or composite materials melting at lower temperature than the operating temperature of the emitter (F),

where the coating layer (Au) is sufficiently thin to copy the profile of the structured part of the first material (W), to form therewith said grating (R), and the second material (Au) has a greater emission efficiency than the first material (W), said efficiency being defined as the ratio between the fraction of visible radiation emitted at the operating temperature in the interval 380 nm - 780 nm and the fraction of radiation emitted at the same temperature in the

interval 780 nm - 2300 nm.

12. An emitter as claimed in claim 10, characterised in that

5 - said grating (R) is obtained on the surface of a layer (Au) of a first conductor, semiconductor or composite material whose melting point is lower than the operating temperature of the filament (F),

10 - said layer (Au) is placed on a second conductor material (W) whose melting point is higher than the operating temperature of the emitter (F),

where the first material (Au) has higher emission efficiency than the second material (W), said efficiency being defined as the ratio between the fraction of visible radiation emitted at the operating temperature in the interval 380 nm - 780 nm and the fraction of radiation emitted at the same temperature in the interval 380 nm - 2300 nm.

13. An emitter as claimed in claim 10, characterised in that said grating (R) is obtained with

20 - a layer of refractory oxide (OR) having a structure part,

25 - a coating layer (Au) which covers at least the structured part of the layer of refractory oxide (OR), the coating layer being of a material (Au) selected among conductor, semiconductor or composite materials melting at lower temperature than the operating temperature of the emitter (F),

30 where the coating layer (Au) is sufficiently thin to copy the profile of the structured part of the first material (W), to form therewith said grating (R), and where the coating layer (Au) is in turn coated by an encapsulating layer constituted by refractory oxide (OR).

14. An emitter as claimed in claim 3, characterised in that at least a throat or cavity (G) is provided,

open on the material constituting the emitter (F) and defined in at least one among said electrodes (H) and said refractory oxide (OR), the cavity or cavities (F) provided being operative to receive part of said material as a result of volume expansions thereof and/or to avoid delamination phenomena between said refractory oxide (OR) and said material and/or ruptures of the complex constituted by said material, said refractory oxide (OR) and said electrodes (H).

10       **15.** An emitter as claimed in claim 10, characterised in that the periodicity of the micro-projections (R1, R2) or of the micro-cavities (C) is of the order of the wavelength of visible radiation.

15       **16.** An emitter as claimed in claim 10, characterised in that the periodicity of the micro-projections (R1, R2) or of the micro-cavities (C) is between 0.2 and 1 micron.

20       **17.** An emitter as claimed in claim 10, characterised in that the height or depth of the micro-projections (R1, R2) or of the micro-cavities (C) is between 0.2 and 1 micron.

**18.** An emitter as claimed in claim 1, characterised in that said anti-reflection micro-structure (R) is binary, i.e. with two levels.

25       **19.** An emitter as claimed in claim 1, characterised in that said anti-reflection micro-structure (R) is multi-level, i.e. it has a projection with more than two levels.

30       **20.** An emitter as claimed in claim 1, characterised in that said anti-reflection micro-structure (R) has a continuous projection.

35       **21.** An emitter as claimed in any of the previous claims, characterised in that it operates at a lower temperature than the melting point of the refractory oxide (OR)..

22. An emitter as claimed in any of the previous claims, characterised in that it is configured as a filament or planar plate structured under the wavelength of visible light, and in that said anti-  
5 reflection micro-structure (R) is a two-dimensional grating of absorbing material ( $k > 1$ ).

23. A method for constructing an emitter capable of being brought to incandescence by the passage of electric current, comprising the steps of:

- 10 a) constructing a template of porous alumina,
- b) infiltrating the template of porous alumina with a material destined to constitute the emitter (F), in such a way that the alumina structure serves as a mould for at least part of an anti-reflection micro-structure  
15 (R) of the emitter (F),
- c) and possibly
  - c1) subsequently eliminating the alumina structure, or
  - c2) maintaining the alumina structure on the  
20 anti-reflection micro-structure (R) and depositing a refractory oxide (CR) onto the remaining part of the emitter (F) destined to extend between two respective terminals (H).

24. A method as claimed in claim 23, where the step  
25 a) comprises the deposition of an aluminium film, with thickness in the order of one micron, on a suitable substrate and the subsequent anodisation thereof, said anodisation comprising at least:

- a first phase of anodisation of the alumina film;
- 30 - a phase of reducing the irregular alumina film obtained as a result of the first anodisation phase;
- a second phase of anodisation of the alumina film starting from the residual part of irregular alumina not eliminated by said reduction phase.

35 25. A method for constructing an emitter capable of.

being brought to incandescence by the passage of electric current, comprising the steps of:

- obtaining a filiform or laminar element of the material whereof the emitter is to be made (F);

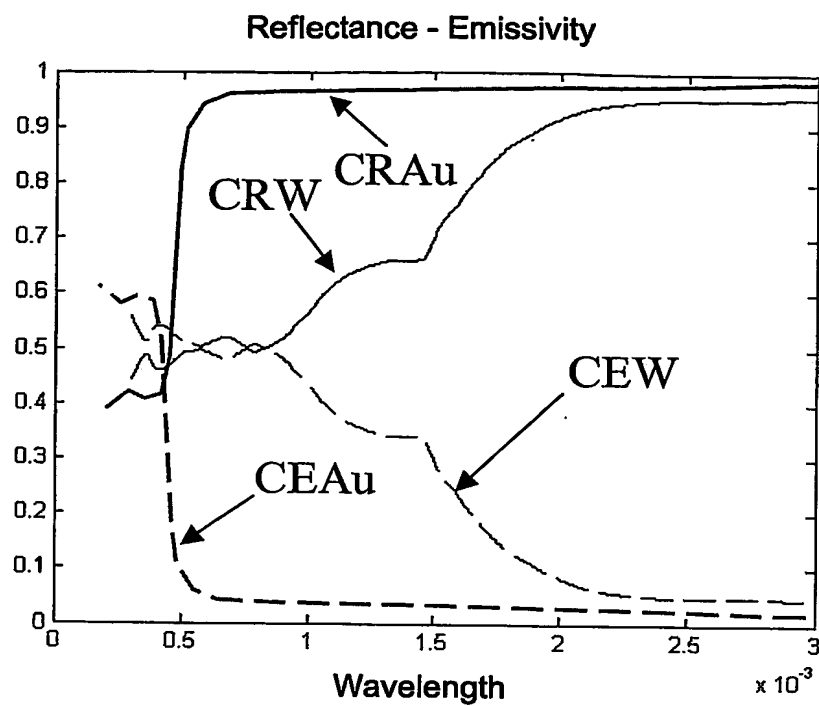
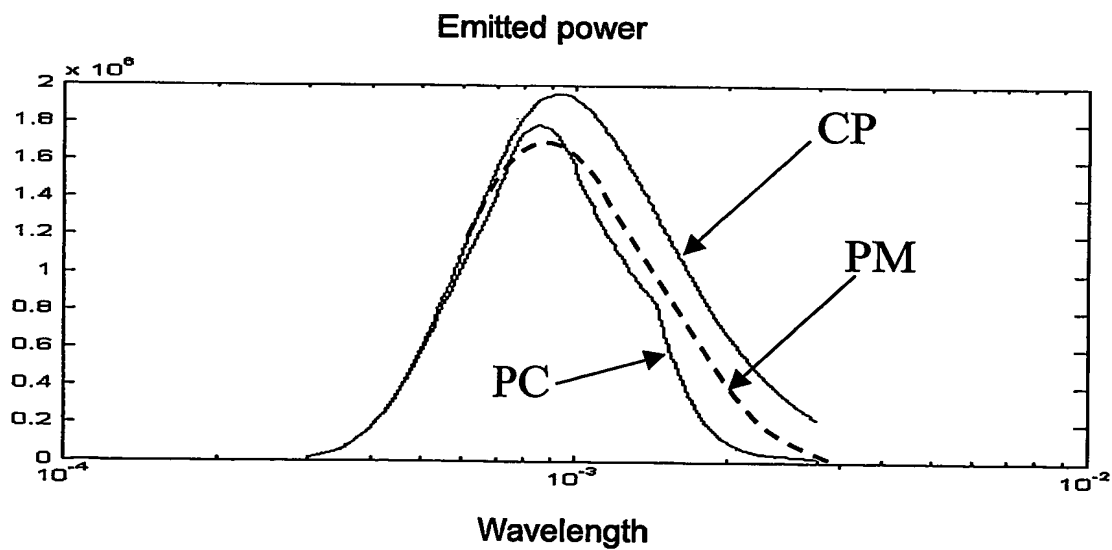
5       - etching said element to form an anti-reflection micro-structure (R),

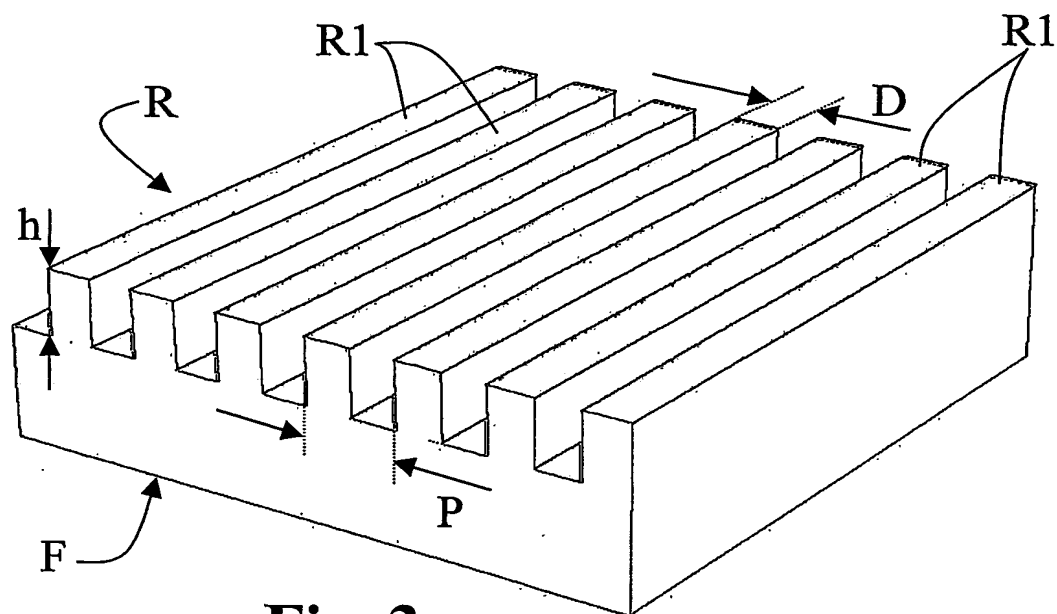
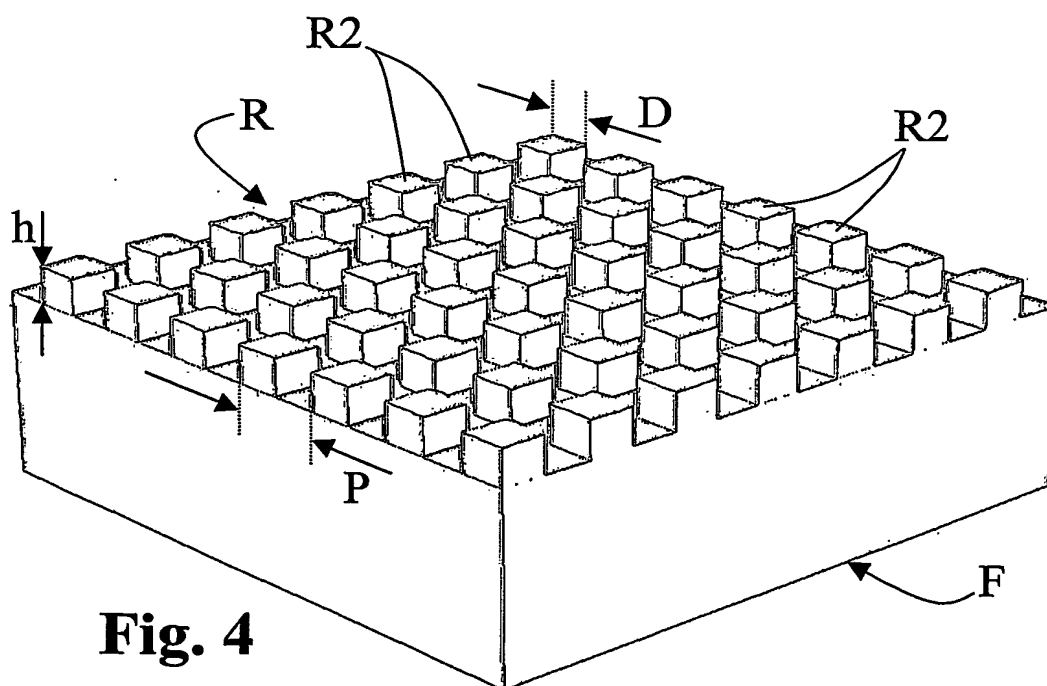
and possibly coating the emitter (F) in which the anti-reflection micro-structure (R) has been formed with a refractory oxide (OR).

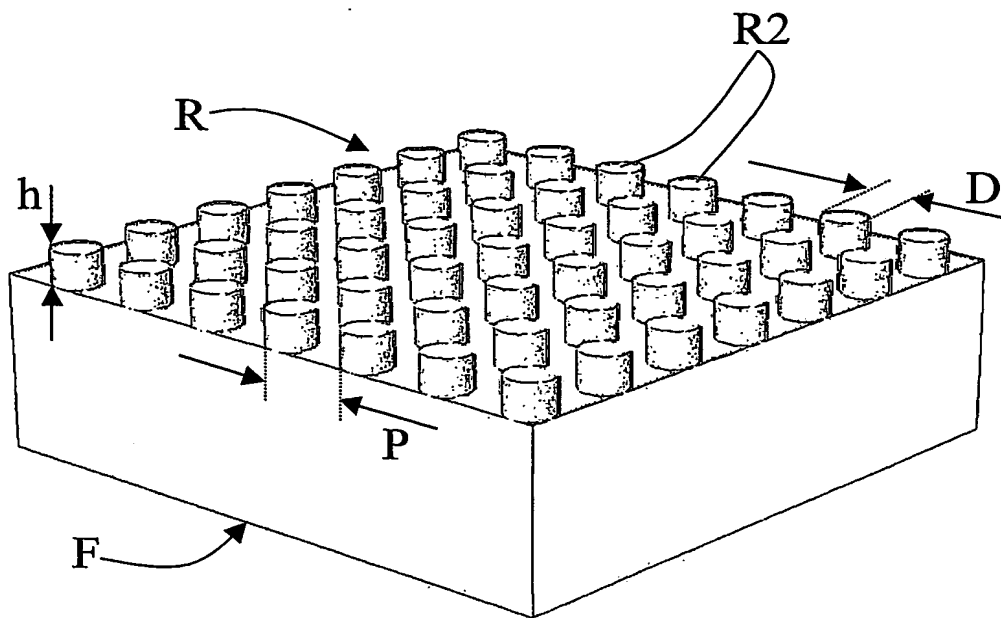
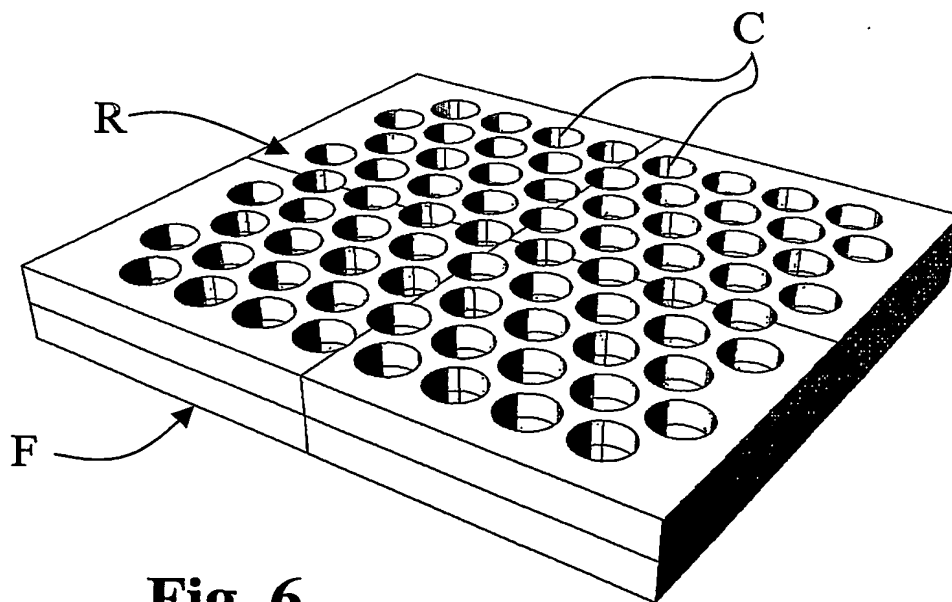
10       **26.** An incandescent light source, comprising a light emitter capable of being brought to incandescence by the passage of electric current, characterised in that said emitter (F) is as claimed in one or more of the claims from 1 through 22.

15       **27.** A lighting device, in particular for motor vehicles, comprising one or more light sources (1) as claimed in claim 26.

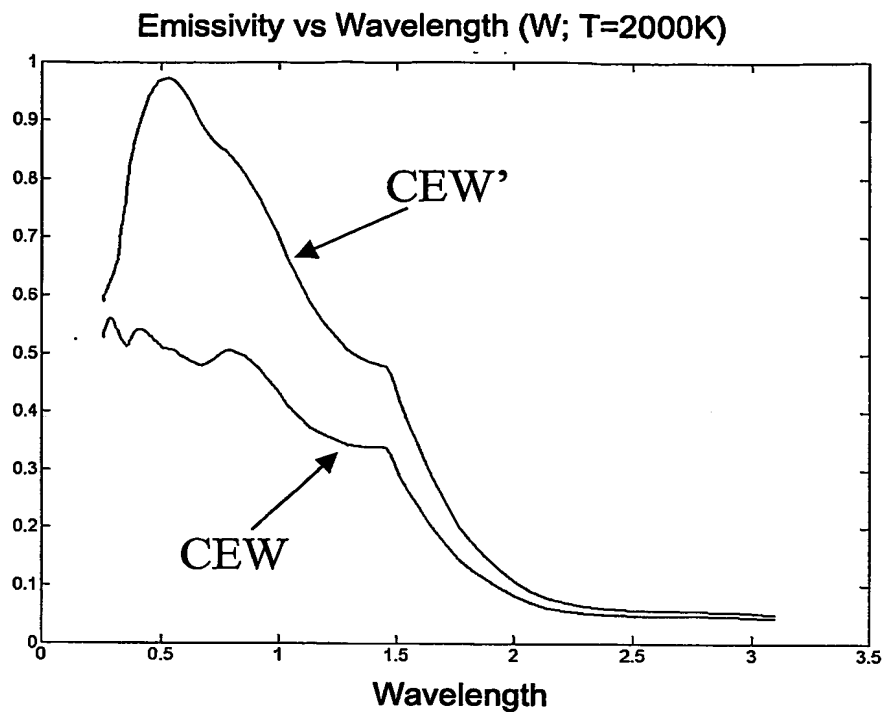
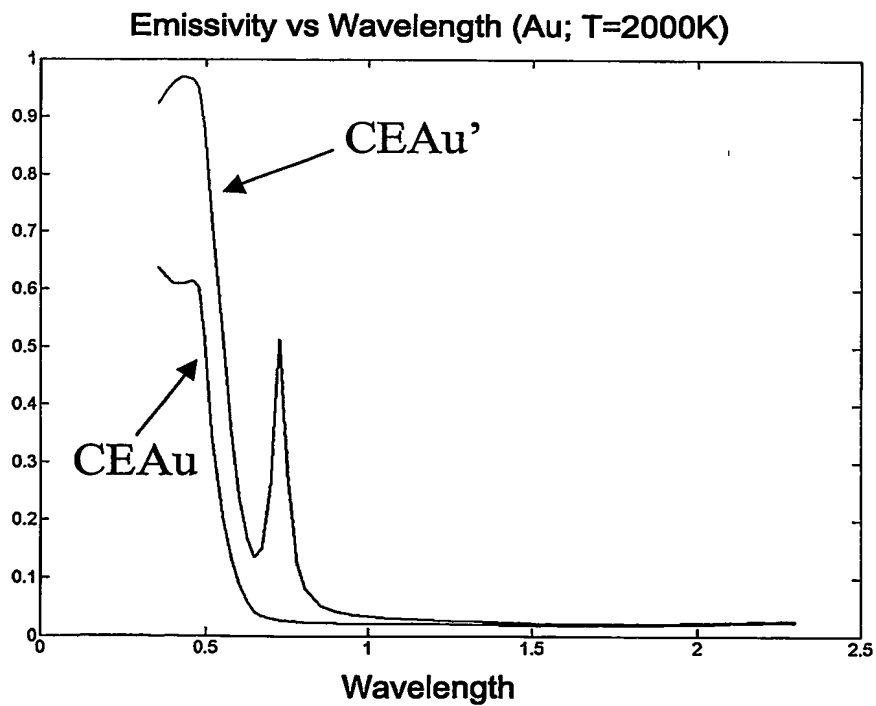
20       **28.** A planar matrix of micro-sources of incandescent light, each comprising a respective emitter (F) as claimed in one or more of the claims 1 through 22.

**Fig. 1****Fig. 2**

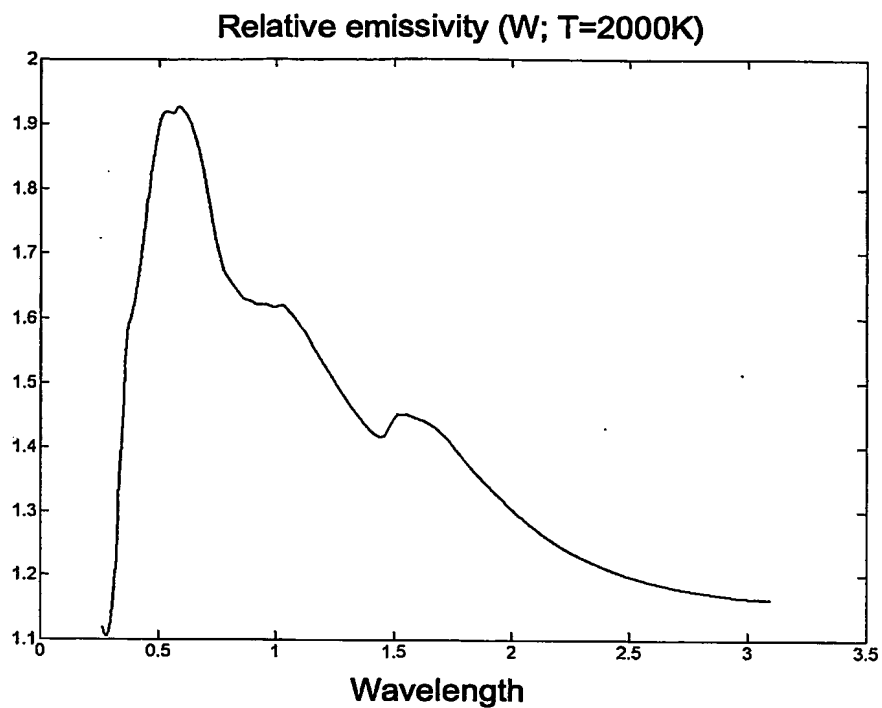
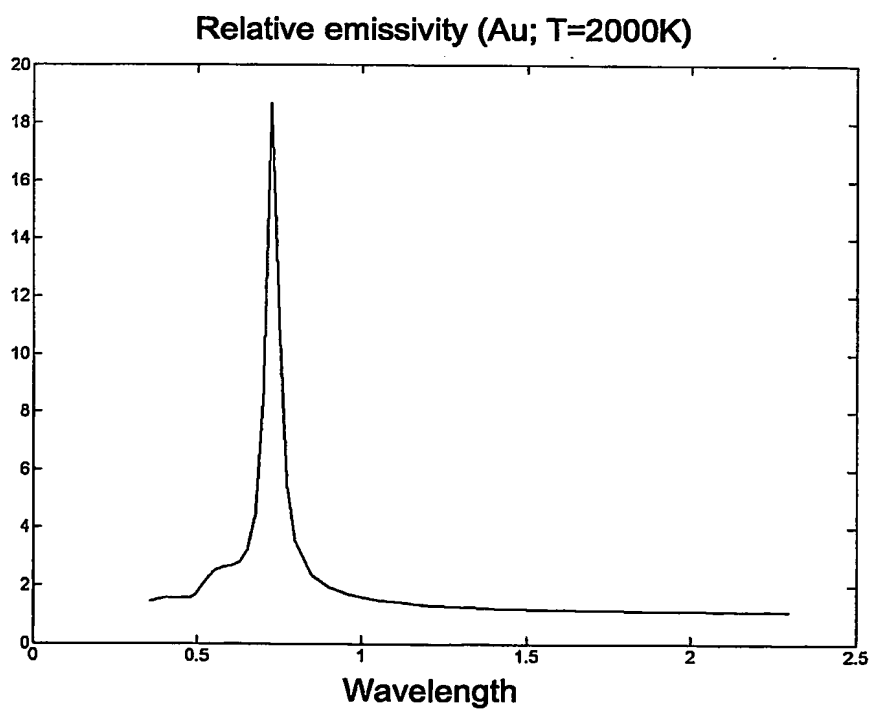
**Fig. 3****Fig. 4**

**Fig. 5****Fig. 6**

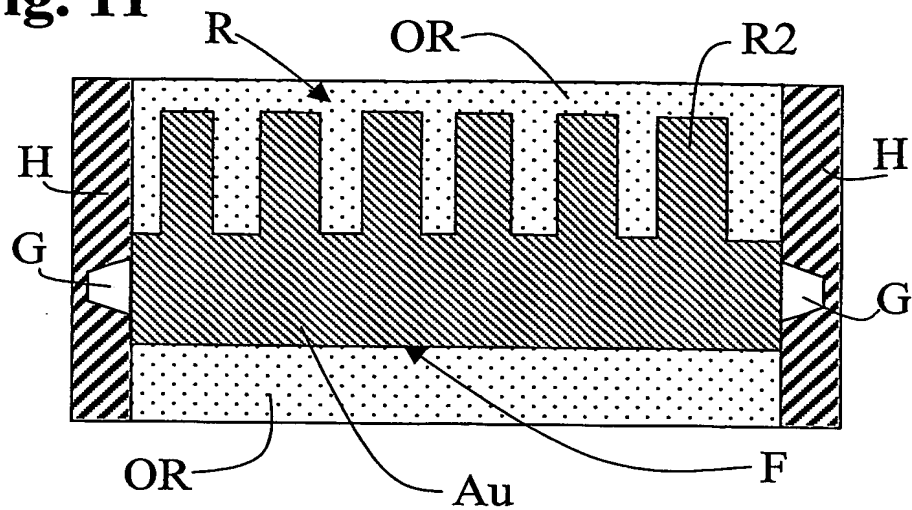


**Fig. 7****Fig. 8**

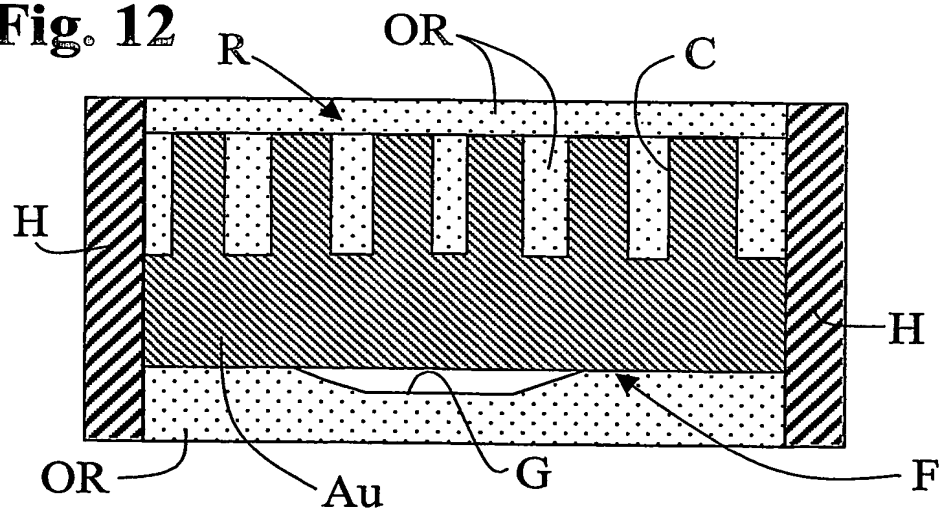
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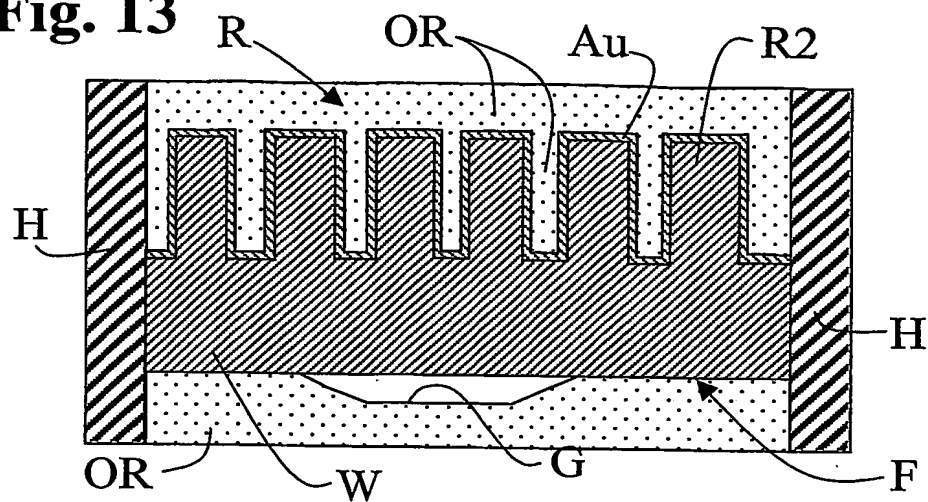
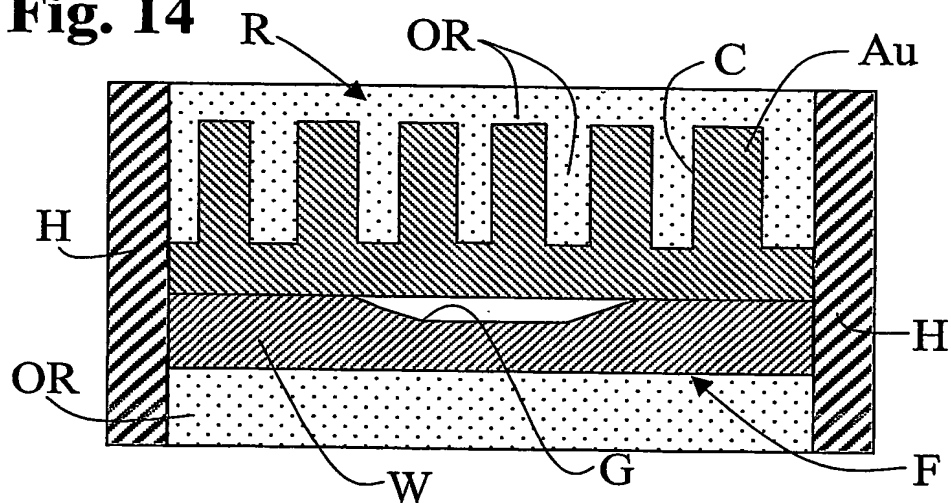
**Fig.9****Fig. 10**

**Fig. 11**



**Fig. 12**



**Fig. 13****Fig. 14****Fig. 15**